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Gas turbine with rotor crack vibration diagnostics

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imagination at work

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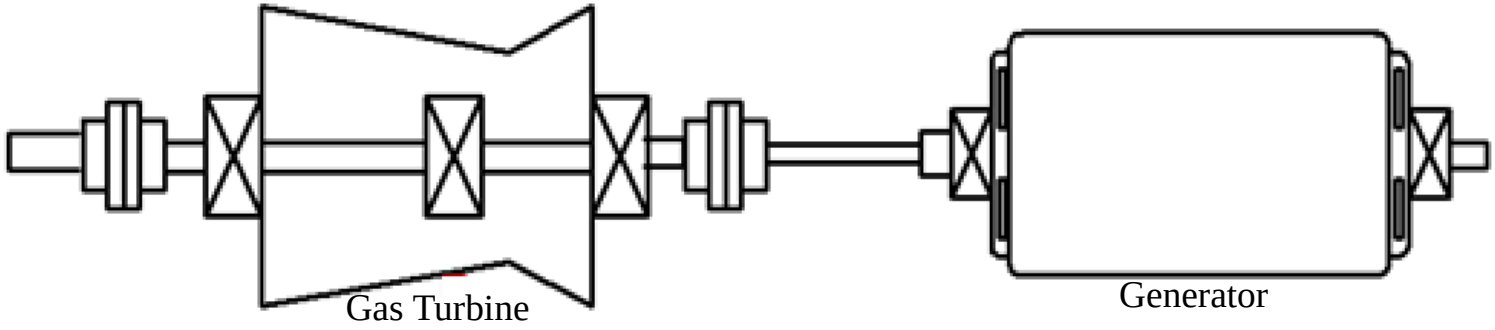
Abstract

The case study describes rotor crack detection using vibration measurements, documented on real case of heavy duty Gas Turbine. The study highlights the complexity of rotor crack diagnostics as the primary problem as it can be often masked by other existing machine malfunctions, such as unbalance, misalignment, bearing looseness or soft foot. The presentation describes the detected symptoms of rotor crack: increase of rotor bow demonstrated by changes in slow roll vectors, decrease in rotor modal stiffness demonstrated by decrease in resonance frequency, the decrease in effective damping, appearance of the split resonance in the rotor shut down not present during the start up, the unidirectional changes in the rotor bow and the repeatability of abnormal-unidirectional rotor response.

Machine train: Gas Turbine - Generator

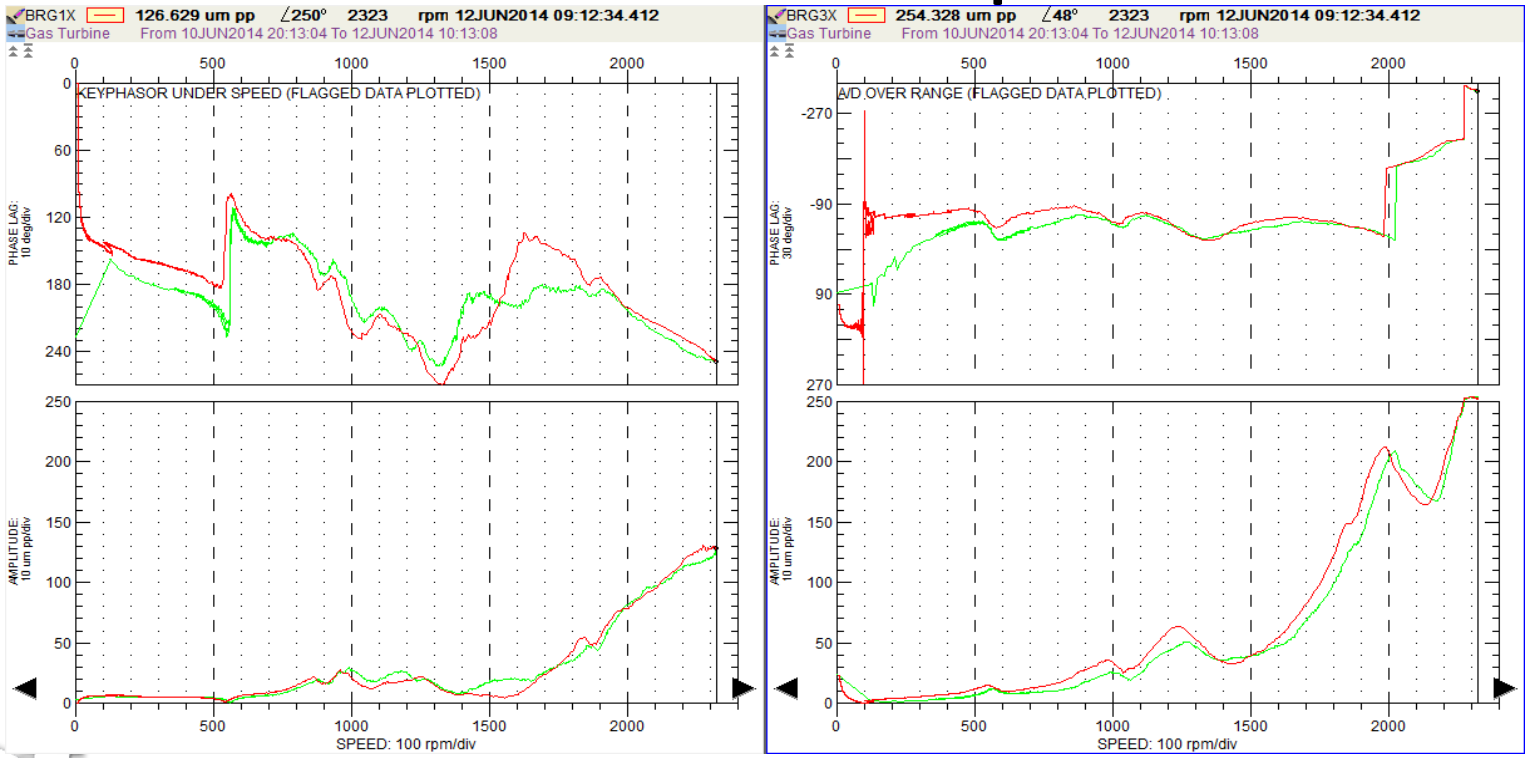


The machine train consists of a single-shaft heavy duty Gas Turbine (120MW, 3000rpm, in service since 1998) directly rigidly coupled on hot end to a synchronous generator. The compressor portion of the gas turbine rotor consists of stacked blade wheels held with tiebolts and it is connected to the turbine rotor via marriage joint. The turbine rotor consists of three turbine wheels with buckets held together with through bolts. The rotor is supported by three main journal bearings (Brg.1,2 Elliptical, Brg.3 tilting pad).

History / Scope of the job

- History none – no permanently installed diagnostics system
- Control System on site with direct trends only
- High vibration during start up – machine trip
- Scope of the job - balancing

First Start up



During Start up, the unit reached the trip levels at bearing 1 vertical seismic transducer (28.8mm/s pk) at 2221rpm and was tripped manually.

First Conclusions

- the coupling balancing is suggested in the first step to pass the resonance
- after unit can pass the critical speed the next evaluation of the alignment for machine hot conditions is recommended.
- bearing 3 looseness, soft foot suspected

First Step: Balancing

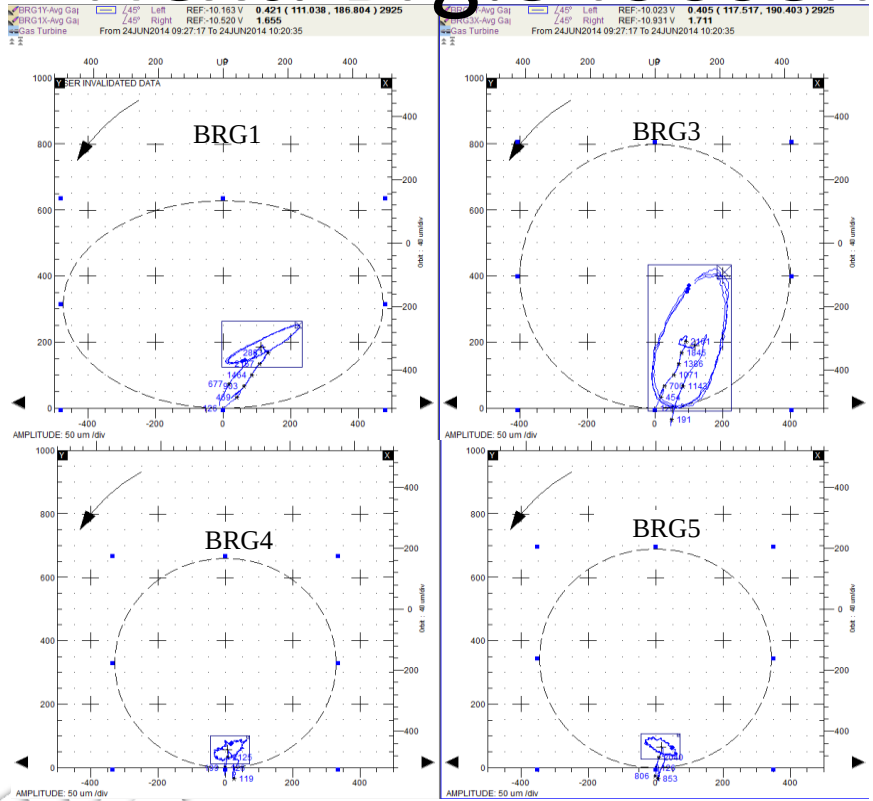
Date	Start Up No.	Bal. Run	Weight Installed	Weight Removed	Resultant W for calculatio	Weight on Generator Brg5 couplir Balancing Plane	Weight on Generator Brg4 couplin Balancing Plane	Weight on GT Brg1 aux.coupling Balancing Plane	Note Load 0deg Reference Brg1V transducer
JUN16	SU3	1	-	803g@0	-		-		Repeated Original Run, FSNL, 3000rpm
JUN16	SU4	3	1030g@45	-	1030g@45		H2:555g	-	Calibration Run2, trip at 2075rpm
							H16:560g		
JUN16	SU5	4	339g@297	1030g@45	339g@297		-	H15:339g	Calibration Run3,
JUN17	SU6	5	350g@180	339g@297	350g@180		H7:350g=175g+175g		Calibration Run4, FSNL+7min
JUN17	SU7	5	350g@180		350g@180		H7:350g=175g+175g		Repeated Calibration Run4, FSNL+12min
JUN17	SU8	6	304g@0	350g@180	304g@0	H22:304g=147g+157g			Calibration Run5, FSNL+12min
JUN18	SU9	7	412g@94		412g@94		close to H3:412g		Correction Run1, KPH lost after FSNL
			591g@255	304g@0	591g@255	H15:591g=191g+205g+195g			
JUN18	SU10	7	413g@94		413g@94		close to H3:413g=238g+175g		Repeated Correction Run1
			591g@255		591g@255	H15:591g=191g+205g+195g			
JUN24	SU11	7	413g@94		413g@94		close to H3:413g=238g+175g		Repeated Correction Run1
			591g@255		591g@255	H15:591g=191g+205g+195g			after generator anchor bolts torque correction and Brg3 soft foot correction

Table of balancing weights placement history

Balancing - Generator balanced

The Generator successfully balanced and the 1X vibration levels on the Generator bearings are in Zone A, according the ISO 10816-4.

Next: Brg.3 looseness, soft foot check



Bearing Metal temperatures at FSNL:
Brg1=50-52deg C
Brg2=68-70deg C
Brg3=48-49deg C
Brg4=76-72deg C
Brg5=68-68deg C

SCL position in bearing 3,4 abnormally low, metal temp low suggest misalignment Brg 3 orbit shape, extreme size and vertical orientation may be due to lowered stiffness and bearing 3 looseness or soft foot

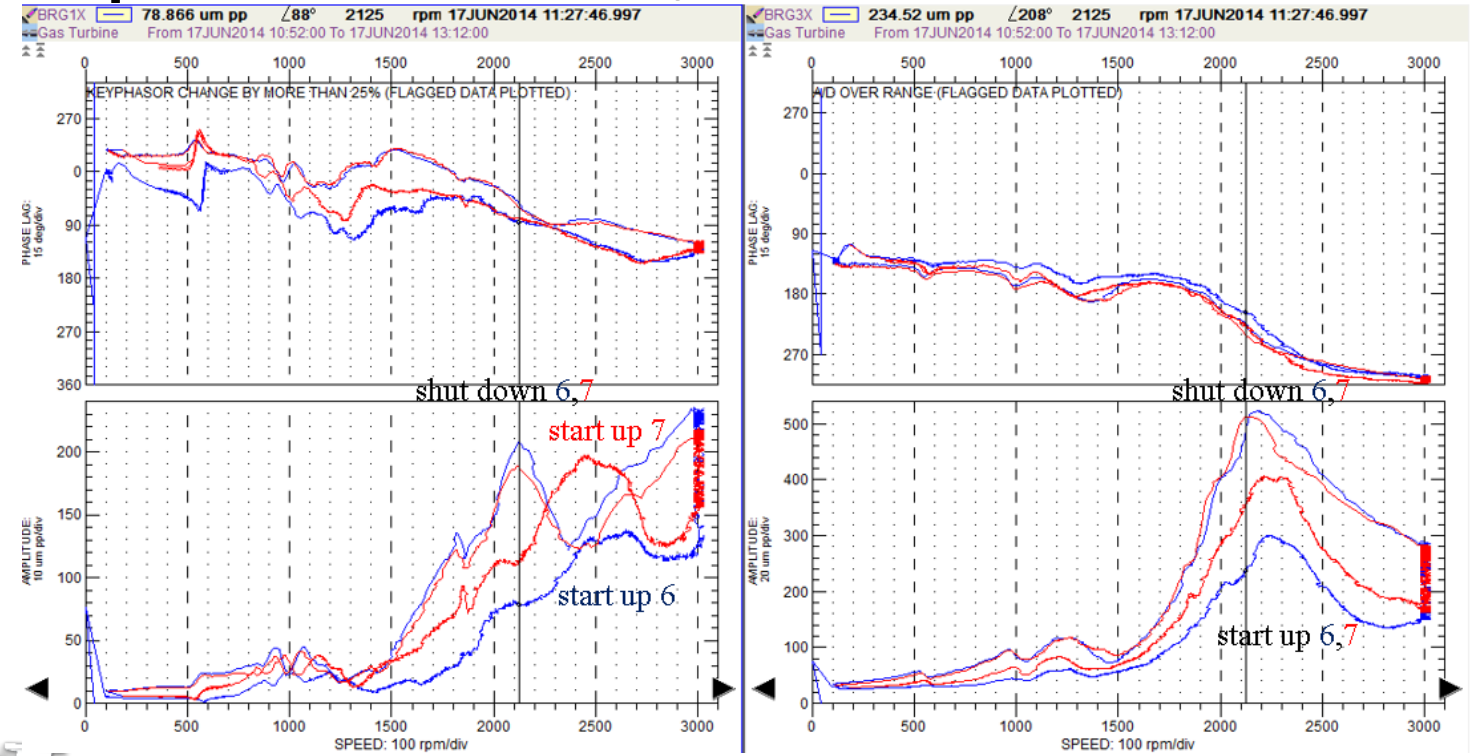
Brg.3 looseness, soft foot

Gas Turbine Bearing 3 base plate shims moved, after reinstalling same height shims, Brg3 base plate raised 200/250um left/right

What was done

- Bearing 3 opened, clearances were checked
- Alignment Gas Turbine – Generator was performed
- Gas Turbine soft foot check performed on all the foots
- Bearing 1 opened, clearances were checked

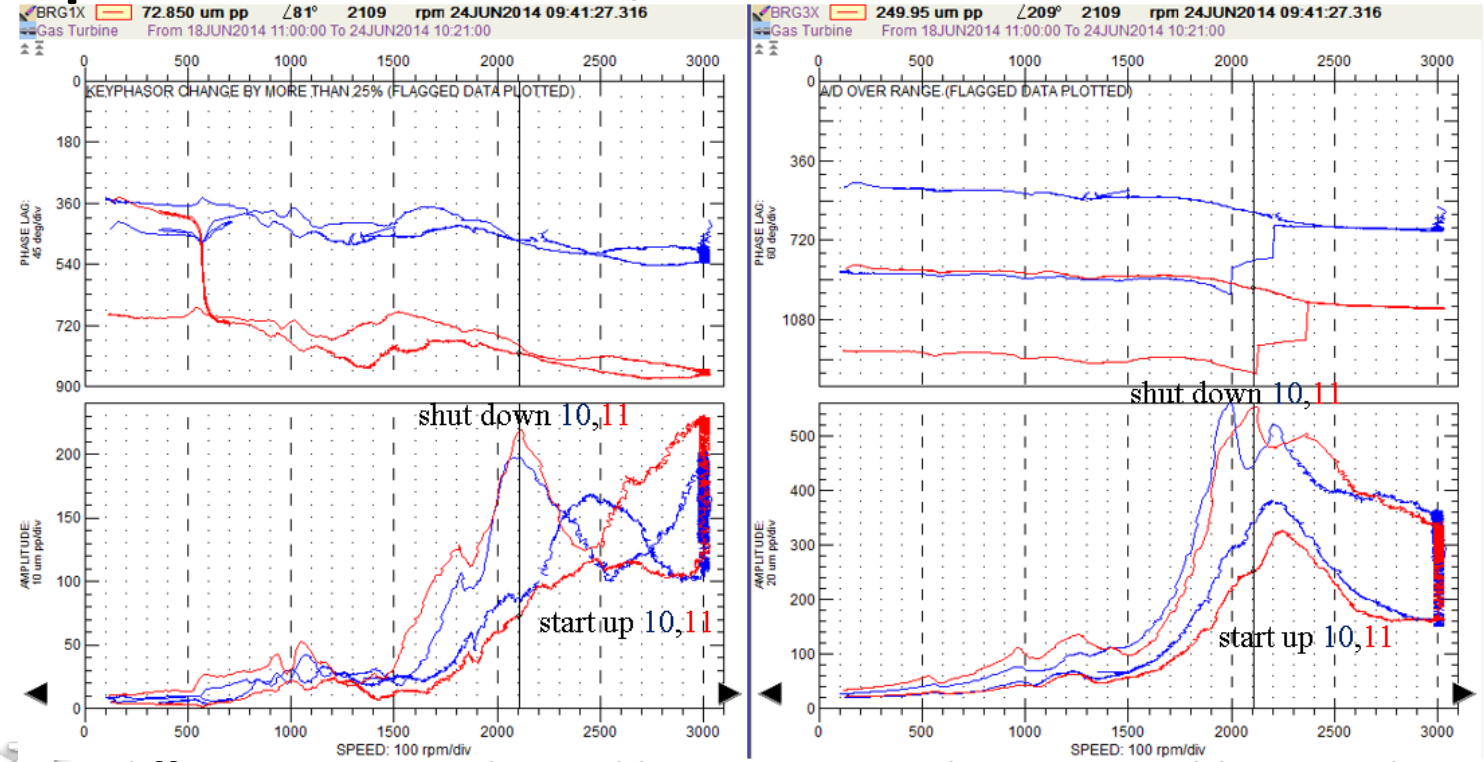
Comparison of 1X, SU/SD6 and SU/SD7



difference in critical speed between SU and SD, repeatable SU and repeatable SD

small change in slow roll

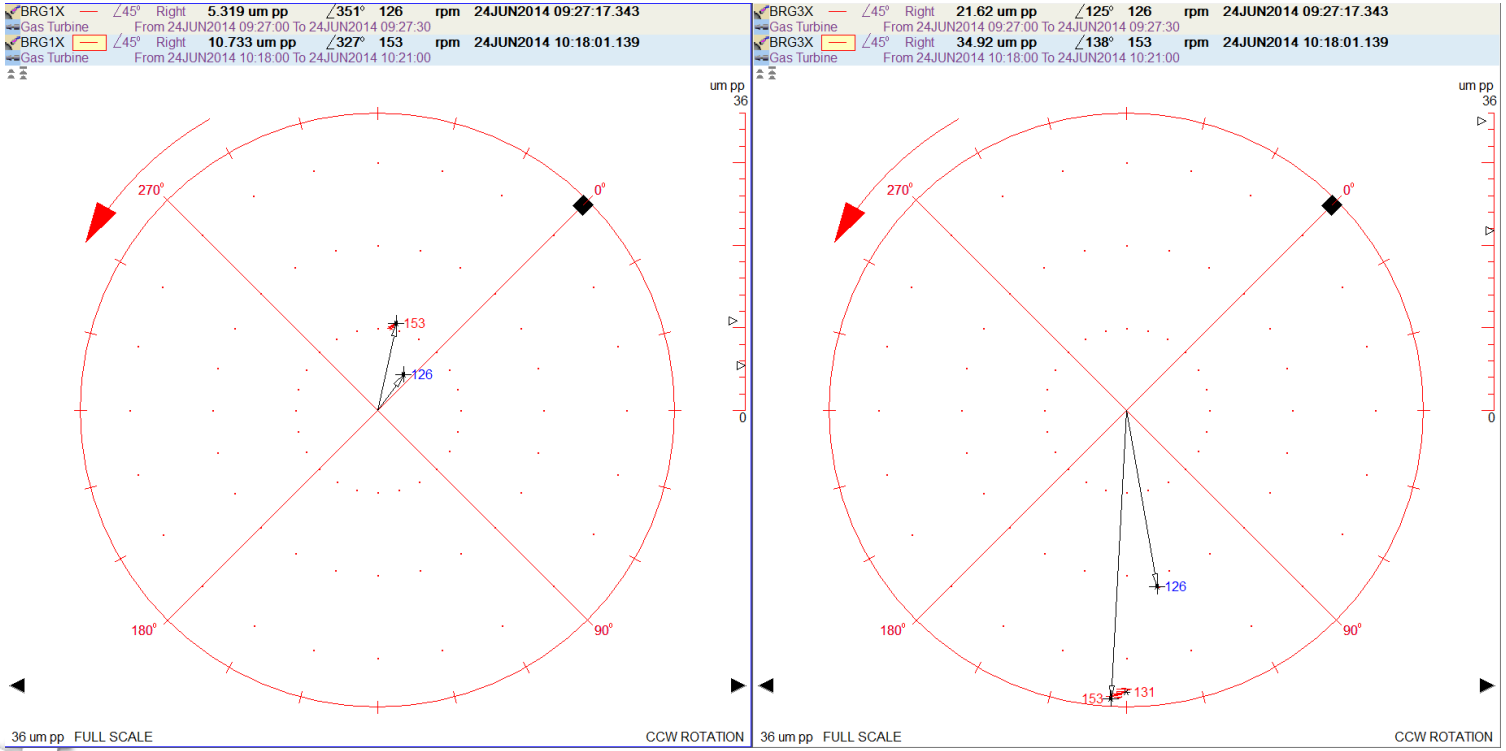
Comparison of 1X, SU/SD10 and SU/SD11



difference in critical speed between SU and SD, repeatable SU and repeatable SD

small change in slow roll (6-14umpp), and split resonance appeared

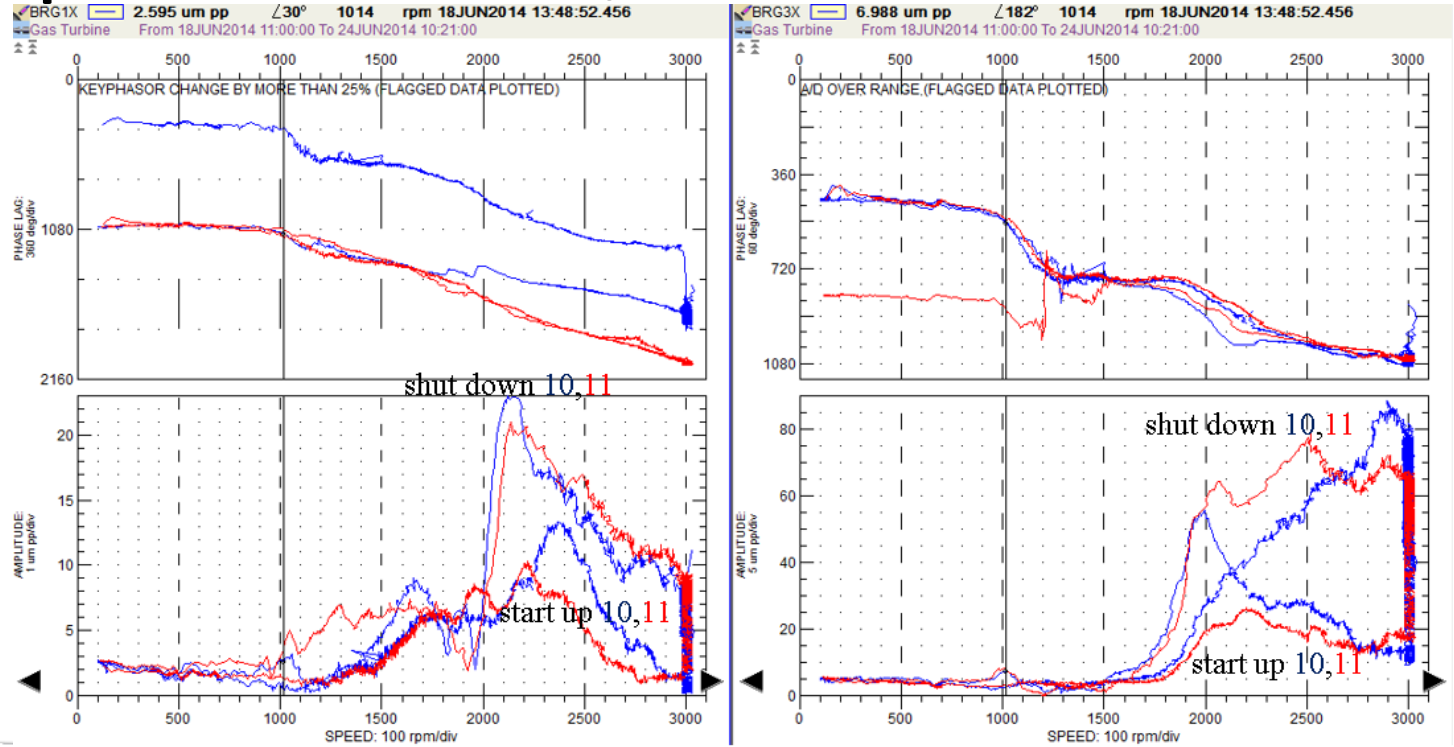
Comparison of 1X, SU/SD10 and SU/SD11



small change in slow roll (6-14umpp)

unidirectional change

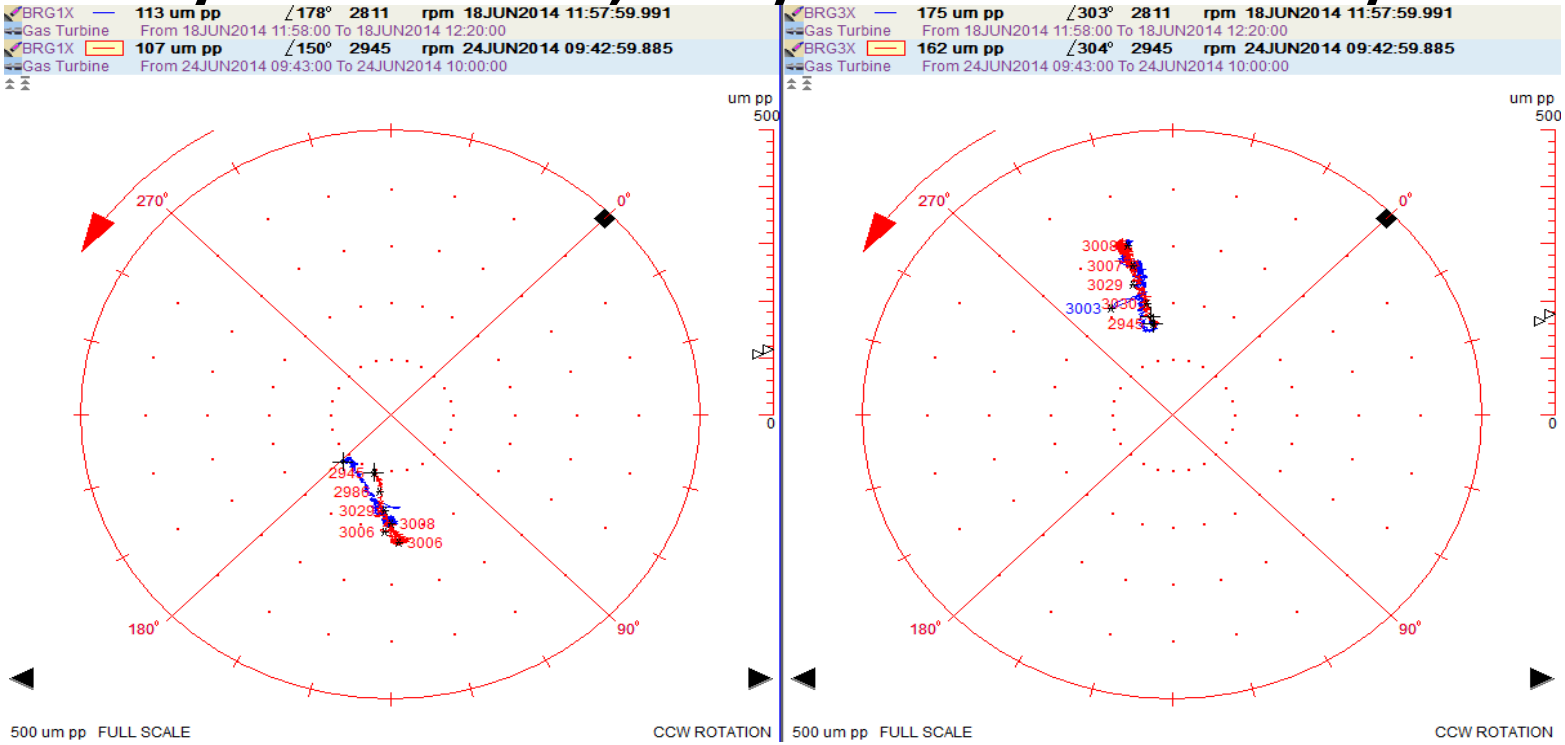
Comparison of 2X, SU/SD10 and SU/SD11



2X component NOT greatly amplified at half of resonance

2X amplified at critical speed is due to Nonlinear Stiffness

Steady State 1X, SU/SD10 and SU/SD11



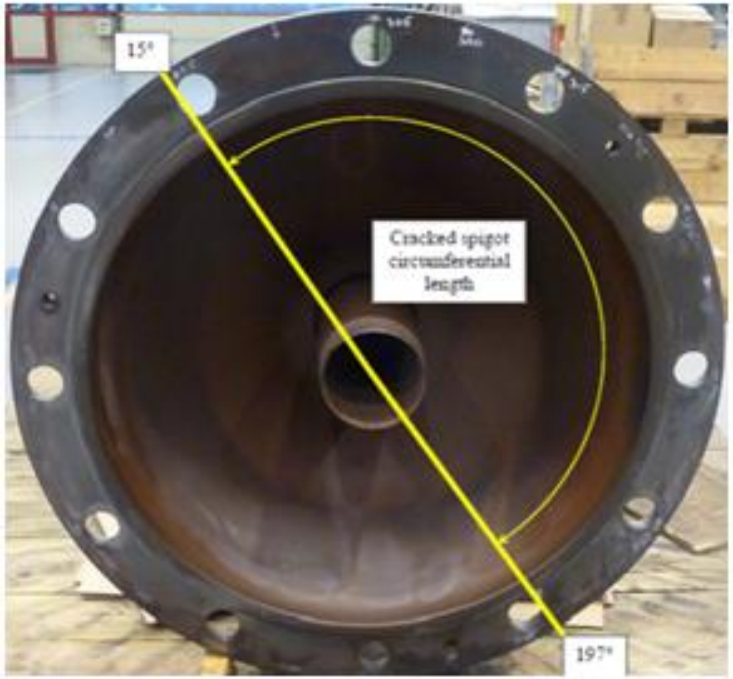
repeatable unidirectional change of 1X vector

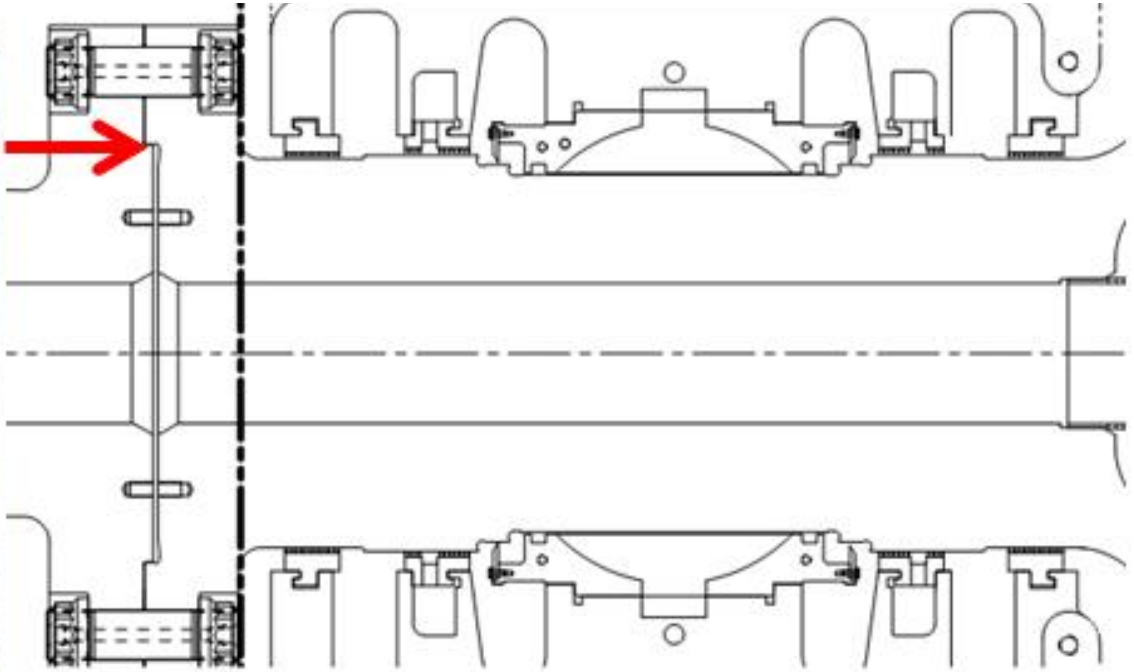
Conclusion - Possible Rotor Crack

- Modified original slow roll rotor response – NOT significant (6-14umpp) in our case
- Unidirectional changes in the rotor bow
- Decrease in rotor modal stiffness demonstrated by decrease in resonance frequency
- Decrease in effective damping demonstrated by higher Synchronous Amplification Factor (SAF)
- Appearance of the split resonance in the rotor start up and shut down data and increase of their span may indicate a pending crack on the rotor [40]. The split resonance during the shutdown, not present during the startup, may suggest the crack propagation.
- Abnormal rotor thermal and load sensitivity – NOT tested on load, only FSNL
- Repeatability of abnormal-unidirectional rotor response

[40] Muszynska, A., Rotordynamics, CRC Taylor & Francis Group, ISBN 0-8247-2399-6, Boca Raton, London, New York, Singapore, 2005, pp. 1-1120.

Gas Turbine Rotor Crack - confirmed





180deg circumferential crack detected, 18mm deep
at the Turbine forward stub shaft, at the marriage joint near the bearing 2
absence of 2X can be possibly explained by lack of radial preload to open the crack, due to vicinity of bearing 2.

End

The case story further showed the difficulty of detecting the rotor crack as primary problem as it can often be masked by other existing machine malfunctions.